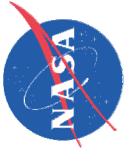


Abstract for submission to Fall MS&T06 Symposium **"Phase Stability, Diffusion and Their Applications"**

Phase Stability of a Powder Metallurgy Disk Superalloy
T. P. Gabb, J. Gayda, P. Kantzos, J. Telesman

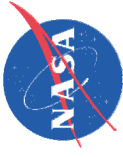
Advanced powder metallurgy superalloy disks in aerospace turbine engines now entering service can be exposed to temperatures approaching 700°C, higher than those previously encountered. They also have higher levels of refractory elements, which can increase mechanical properties at these temperatures but can also encourage phase instabilities during service. Microstructural changes including precipitation of topological close pack phase precipitation and coarsening of existing γ' precipitates can be slow at these temperatures, yet potentially significant for anticipated disk service times exceeding 1,000 h. The ability to quantify and predict such potential phase instabilities and degradation of capabilities is needed to insure structural integrity and air worthiness of propulsion systems over the full life cycle. A prototypical advanced disk superalloy was subjected to high temperature exposures, and then evaluated. Microstructural changes and corresponding changes in mechanical properties were quantified. The results will be compared to predictions of microstructure modeling software.



Phase Stability of a Powder Metallurgy Disk Superalloy

Tim Gabb, J. Gayda, J. Telesman, A. Garg, P. Kantzos

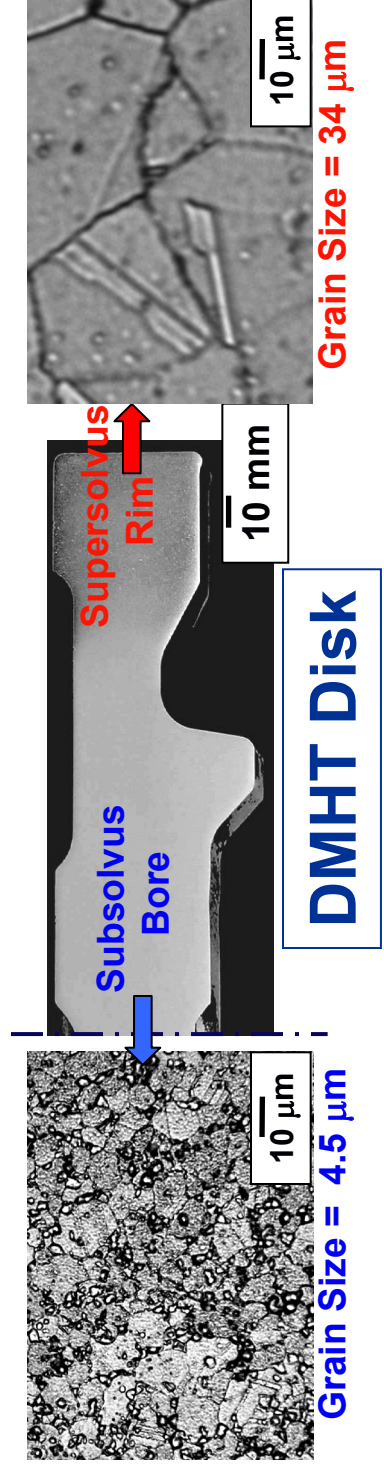
Phase Stability, Diffusion and Their Applications
Materials Science & Technology 2006
October 18, 2006

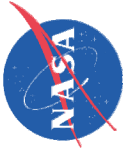


Background

- Powder metallurgy processing of disk superalloys allows higher levels of strengthening elements for increased temperature capabilities
- Advanced dual microstructure heat treatments (DMHT) can also be applied to produce optimal grain size vs. location and associated temperature/stress

- 1) Fine grain size in bore and web sections for high strength and fatigue resistance up to 500°C
- 2) Coarse grain size in the rim for high creep and crack growth resistance at 700°C+

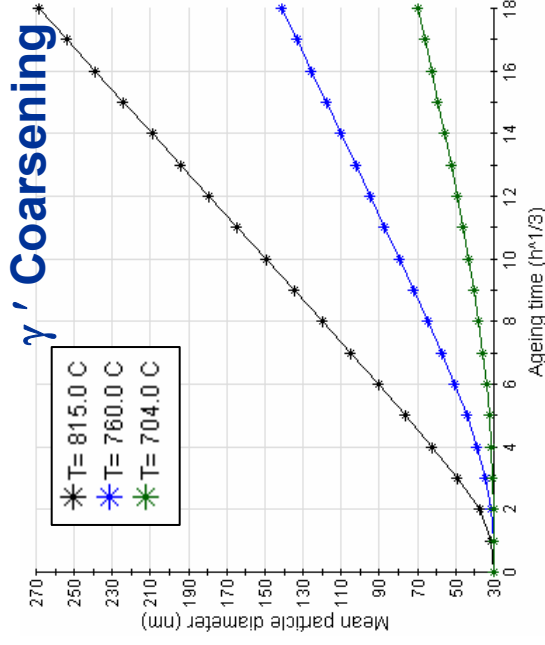
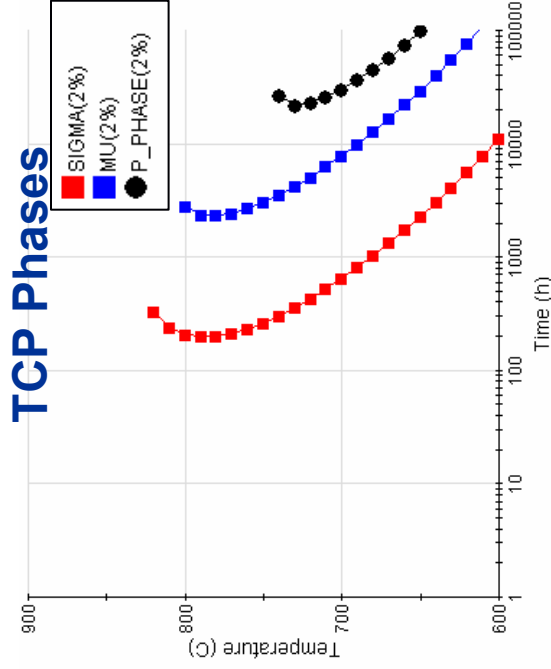




Statement of Problem

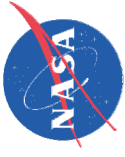
The long term stability of a DMHT rim's microstructure at 700°C+ is a concern

- Commercial software predicts precipitation of harmful phases for DMHT alloy (LSHR)
- Changes of γ' precipitate sizes also predicted
- These effects might be accelerated at grain boundaries



How would these changes effect mechanical properties?

- Tensile properties need to be stable
- Time-dependent properties could limit life at these temperatures
- Grain boundaries are often failure sites here : enhanced effects?



Objective

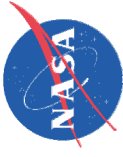
Assess the long term stability of rim mechanical properties and microstructure at 704°C

- **Tensile and time-dependent properties**
- **Presence of harmful phases and coarsening of carbides**
- **Changes of the γ' precipitate sizes and contents**

Approach

Expose blanks from the heat treated rim of a DMHT disk at these temperatures; then machine, test, and analyze specimens

- **Tensile, stress relaxation, and dwell crack growth properties selected for testing**
- **Presence of harmful phases and changes in carbides and γ' precipitates screened using field emission scanning electron microscopy**
- **Initial results for exposures at 704°C up to 5,000 h will be presented**



Material and Procedure

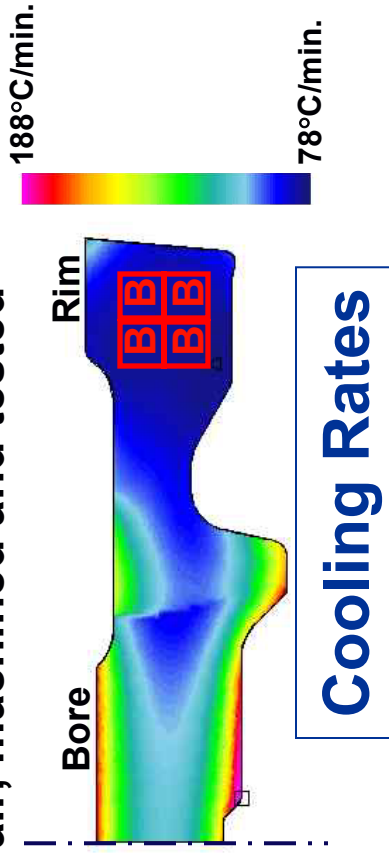
Alloy: NASA LSHR

| Wt% | Al | B | C | Co | Cr | Fe | Mo | Nb | Ta | Ti | W | Zr | Ni |
|------------------|------|-------|-------|------|-------|------|------|------|-----|-----|------|-------|--------|
| LSHR Composition | 3.46 | 0.028 | 0.029 | 20.7 | 12.52 | 0.07 | 2.73 | 1.45 | 1.6 | 3.5 | 4.33 | 0.049 | 49.534 |

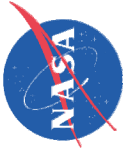
Consolidation: Argon atomized powder, hot compacted, extruded, iso-forged

Heat Treatment: DMHT + Supercool® Air Quench + 855°C/4h + 775°C/8h

Procedure: Blanks (**B**) were extracted from rim of uniform cooling rate and grain size, exposed in air, machined and tested

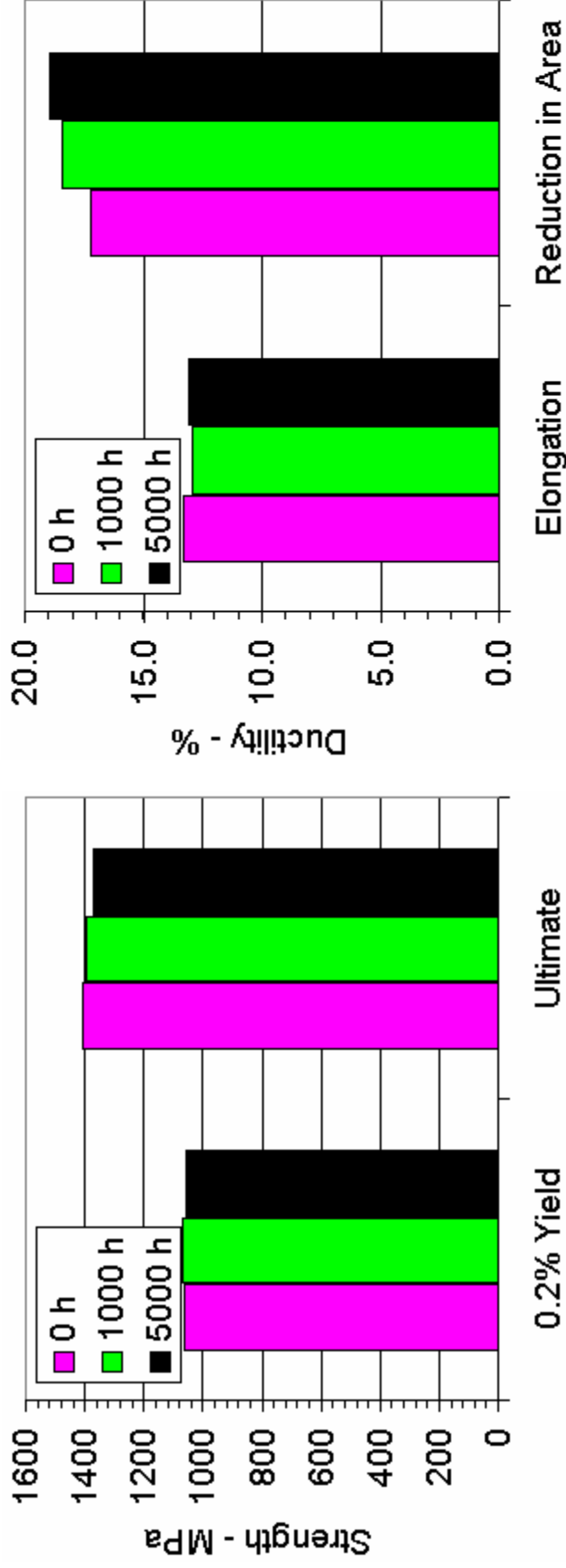


® Ladish Co., Inc.

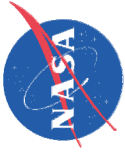


Results

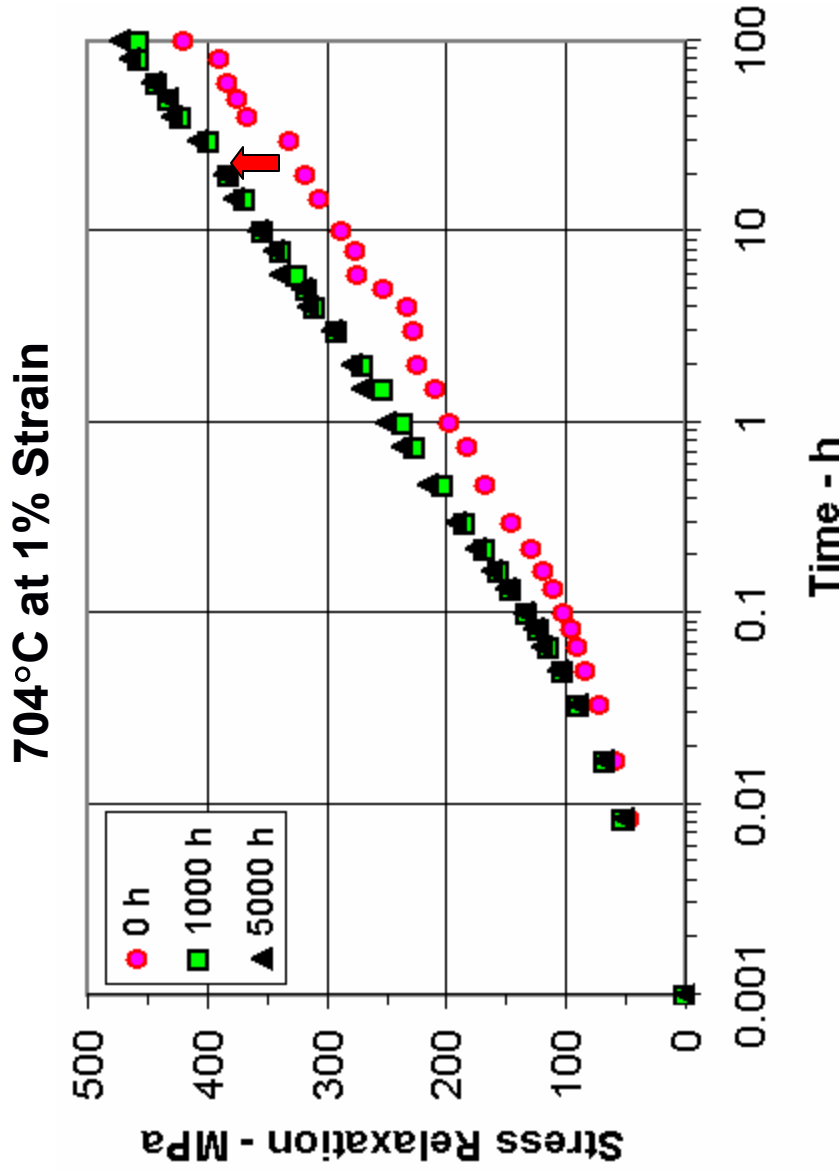
Effects of Exposures at 704°C on Tensile Properties



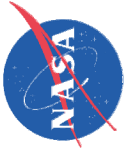
Increasing exposures did not severely degrade properties



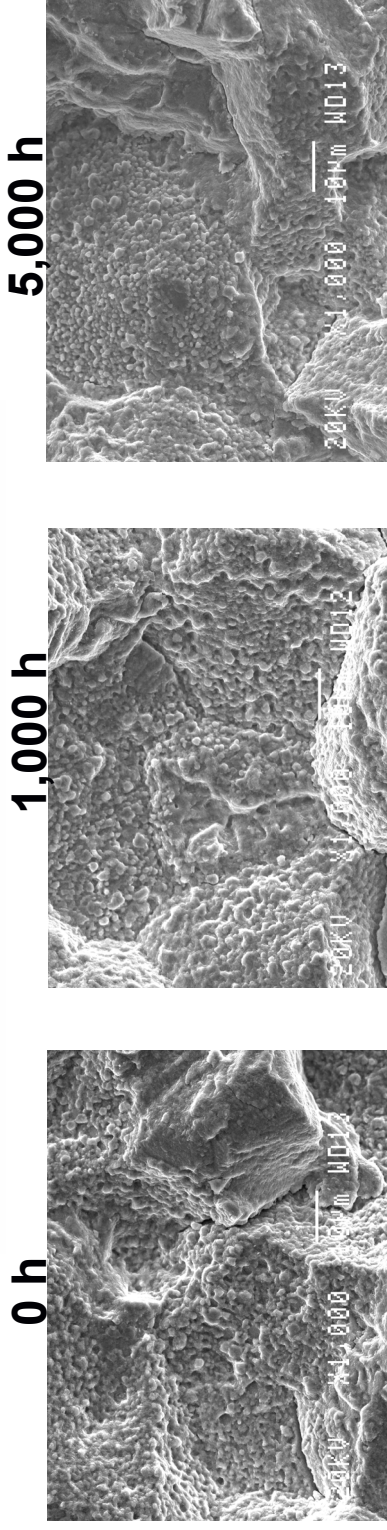
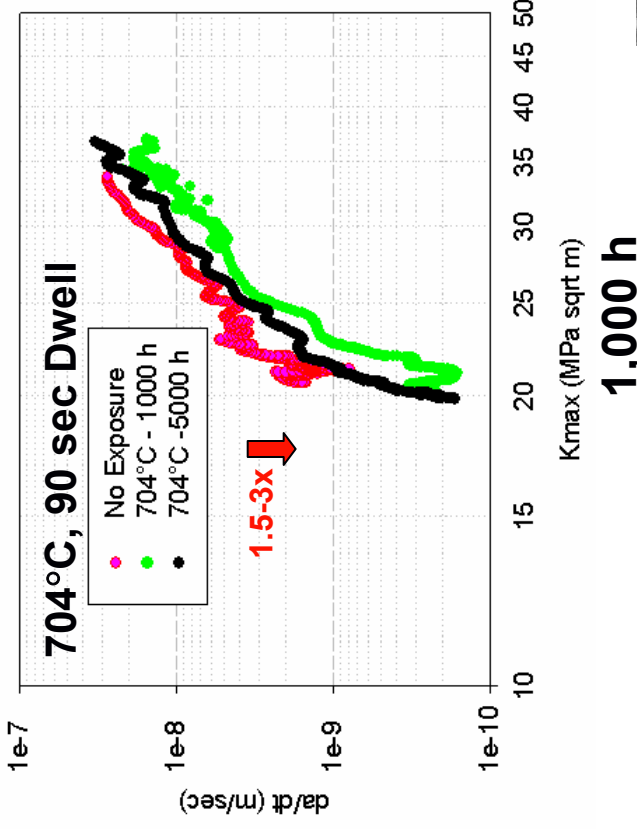
Effects of Exposures at 704°C on Subsequent Stress Relaxation



Increasing exposure allowed more stress relaxation

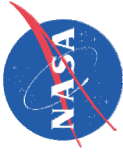


Effects of Exposures at 704°C on Subsequent Dwell Crack Growth Resistance



- Predominantly intergranular crack growth in all cases

Increased exposure improved dwell crack growth resistance



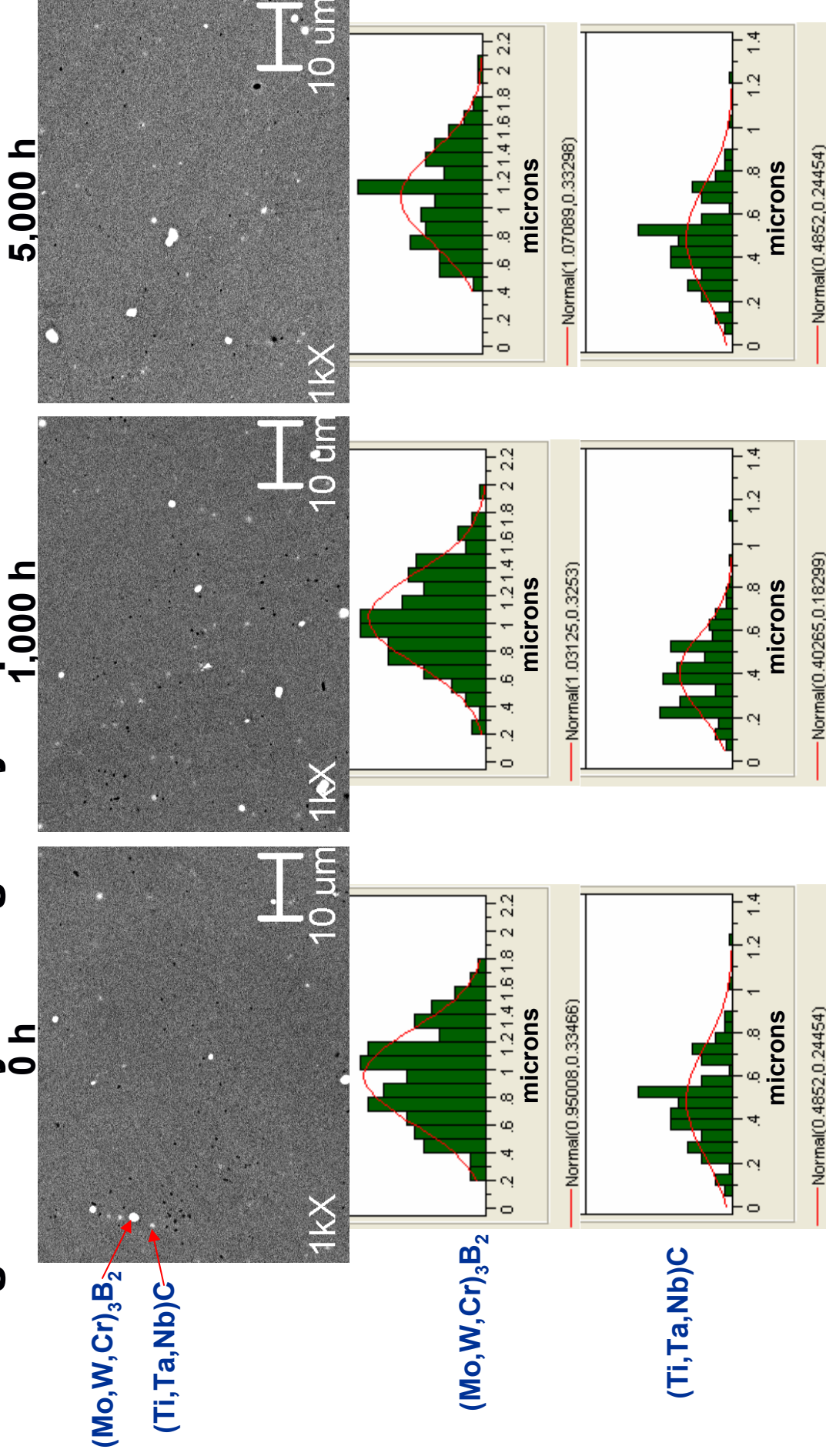
Effects of exposures on mechanical properties

- **Tensile properties: stable, slightly more forgiving**
- **Stress relaxation: more relaxation allowed**
- **Dwell fatigue crack growth: modest improvement**

What are the associated microstructural changes?

- **Minor phase changes**
- **Changes of the γ' precipitate sizes and contents within grains**
- **γ' precipitate changes at the grain boundaries**

Minor Phase Size Distributions and Area Fractions Were Not Significantly Changed By Exposures



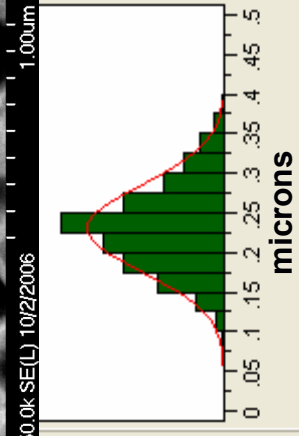
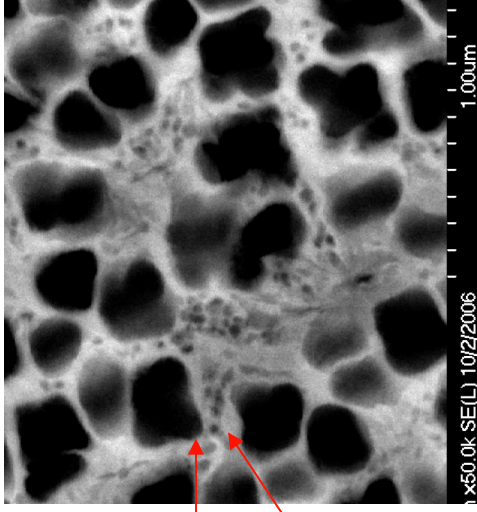
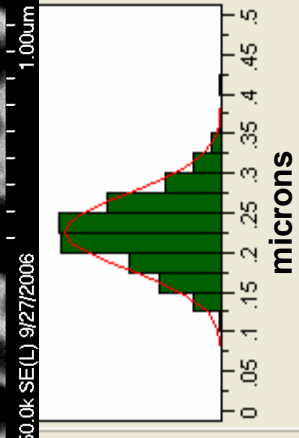
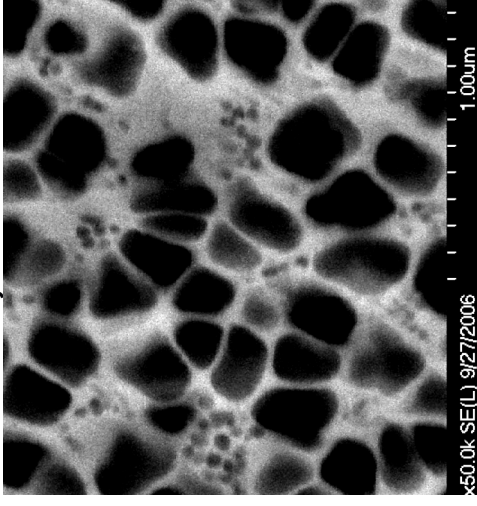
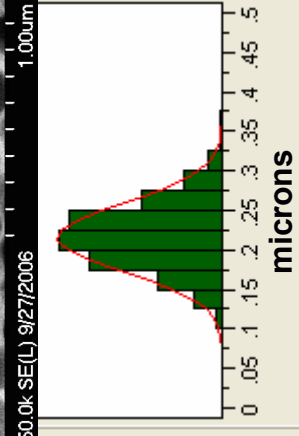
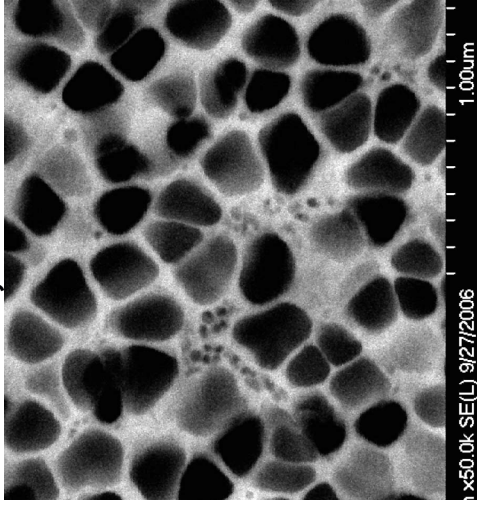
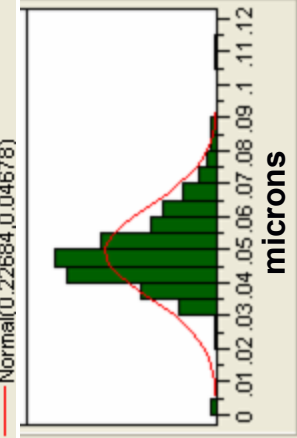
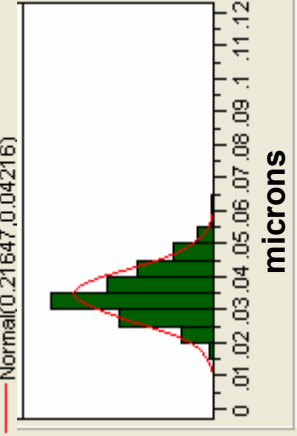
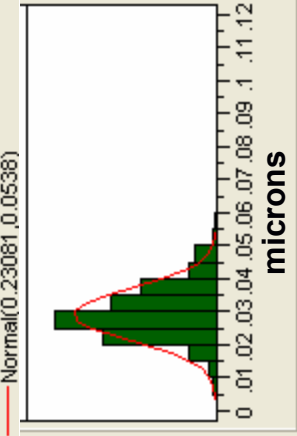
Exposures did not promote harmful phase formation

Secondary γ' Precipitates Were Stable Within Grains

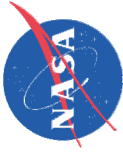
5,000 h

1,000 h

0 h

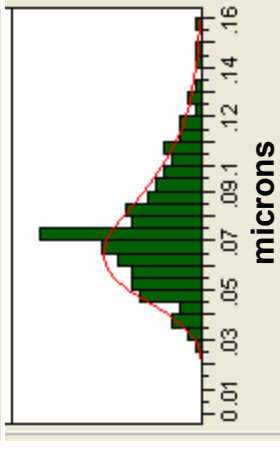
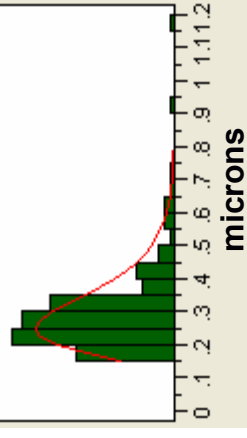
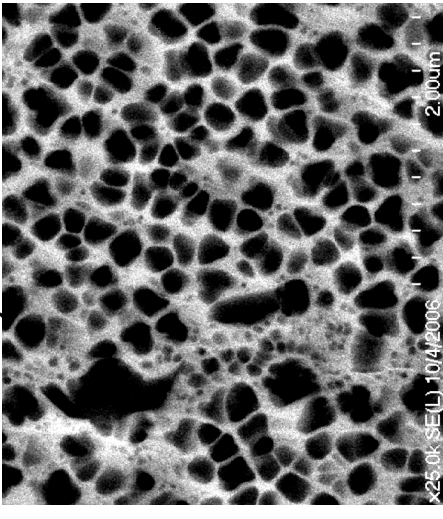
Secondary
 γ' Tertiary
 γ' Secondary
 γ' Tertiary
 γ' 

Tertiary γ' precipitates coarsened

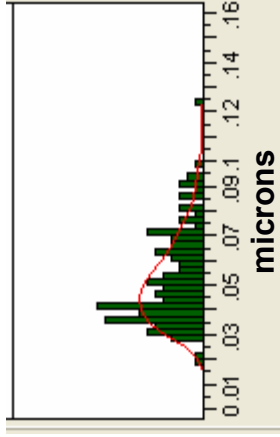
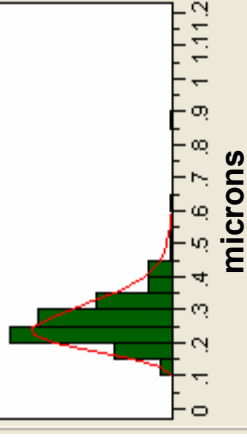
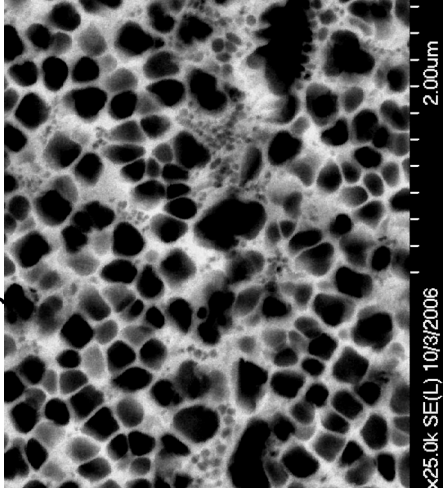


Secondary γ' Was Also Stable At Grain Boundaries

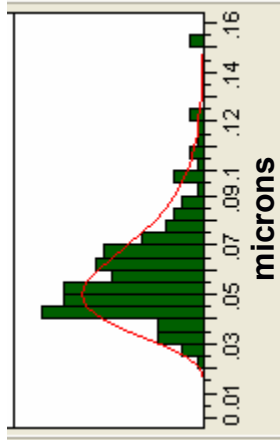
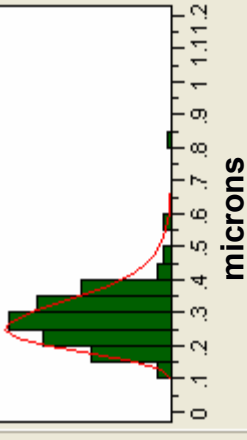
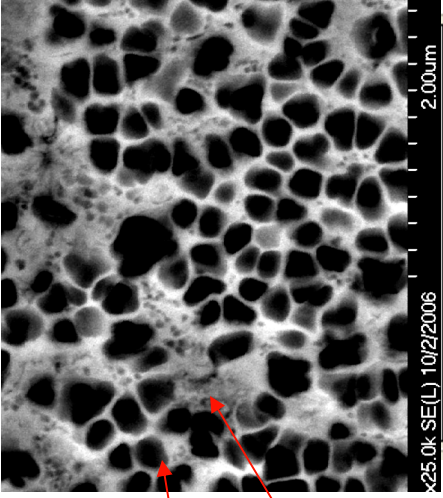
5,000 h



1,000 h



0 h



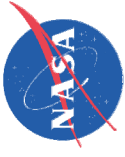
Secondary γ'

Tertiary γ'

Secondary γ'

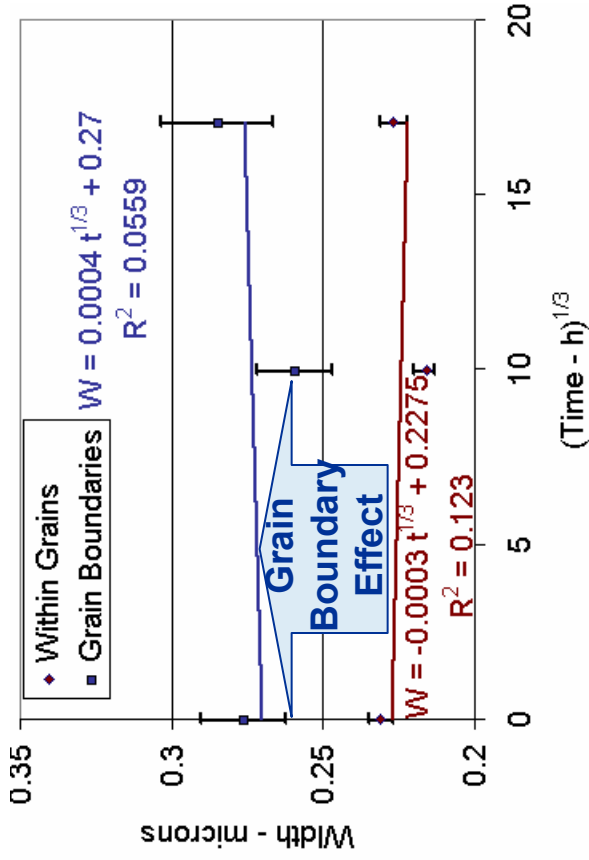
Tertiary γ'

Tertiary γ' precipitates also coarsened at grain boundaries

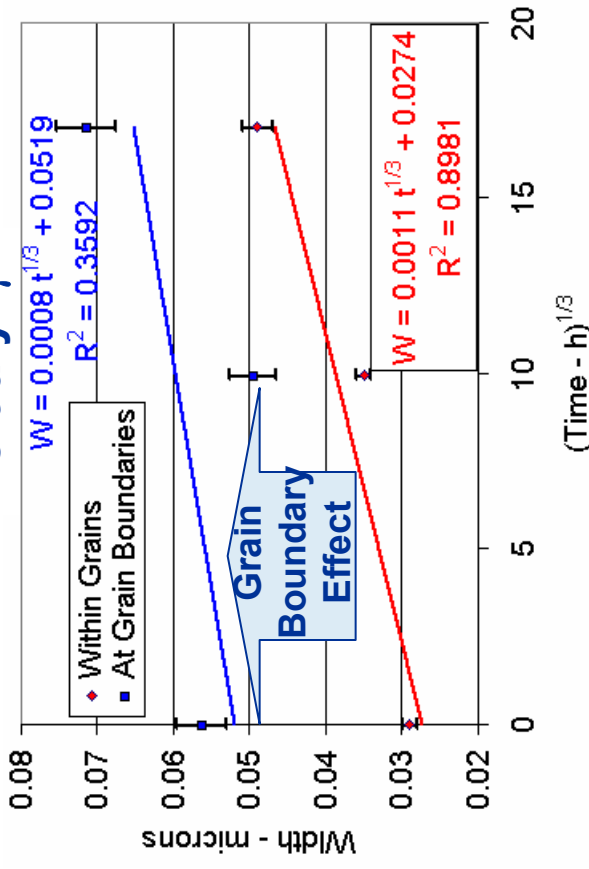


Comparison of Measurements Indicates Tertiary γ' Coarsening Throughout Microstructure Appears Most Closely Associated With The Observed Property Changes

Secondary γ'

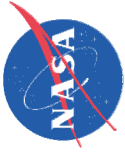


Tertiary γ'



Tertiary coarsening appears near $t^{1/3}$ LSW* dependence

*Lifshitz-Slyozov-Wagner theory



Summary and Conclusions

The long term, high temperature stability of the DMHT rim's microstructure at 700°C+ appears promising so far:

Mechanical Properties

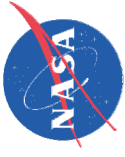
- Tensile properties, time-dependent properties indicate exposures produced a slightly more forgiving material

Microstructure

- No harmful phases found so far, despite model predictions
- γ' phase fairly stable, with only tertiary precipitate coarsening
- Grain boundary microstructure likewise stable so far

Microstructure-Properties

- Exposure effects on mechanical properties appear associated with coarsening of tertiary γ' throughout microstructure
- Secondary γ' size appears largely set through solution heat treat cooling path, note this was previously shown to also effect these properties
- Application of different starting heat treatments and other subsequent exposures and stress could alter these findings



Future Work

- Transmission electron microscopy will be used to more closely study tertiary γ' changes
- Higher temperatures, more exposure times will be explored
- Exposures under stress are planned, to more closely simulate stressed turbine disk locations
- The effects of different heat treatments (cooling rates and ages) on subsequent exposure response also need to be considered
- Modeling of these effects is also getting underway